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STRUCTURAL FIRING TESTS OF THE M735 PROXIMITY FUZE.(U)

MAY 79 J M MILLER, S A BORING

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A structural firing test program, consisting of 37 structural fuze gun firings, was conducted during development of the M735 fuze. The purpose of the test program was to verify the structural adequacy of the M735 fuze. Special structural mockup fuzes were gun fired to minimize costs and to provide overtests of various structural parts. For each fuze design iteration, structural fuzes were assembled and gun fired with various soft

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recovery systems. A number of fuze design changes were based on results of the structural firing tests. The structural firing test program resulted in a lightweight M735 fuze design which met design requirements for a structural factor of safety of 1.5.

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1. INTRODUCTION

The M735 fuze, shown in figure 1, is a state-of-the-art electronic proximity fuze now under development for the M753 8-in. nuclear artillery projectile. Because of the high safety and reliability requirements, complexity of the fuze design, severe gun-firing environmental requirements (10,400 g setback and 190 rps spin), and tight weight and volume constraints, an extensive gun-firing test program of the fuze has been conducted during the development program. In addition to gun-firing tests of fully functional fuzes, a large number of structural firing tests have been conducted. The structural gun-firing test program was an integral part of the structural design process as described below.

Figure 1. M735 fuze.

The first step in the fuze structural design process was the stress analysis of the major structural parts, based on design layouts and drawings. Because of the complexity and constraints mentioned above, an accurate computerized stress analysis was required. Most of the fuze structural parts were analyzed using the National Aeronautics and Space Administration (NASA) Structural Analysis (NASTRAN) computer code.

Successive analysis iterations were performed using highly detailed finite element models in order to accurately predict stress and deflection levels in the various structural parts. Based on the analytical results, structural part drawings were refined and subsequently used for the fabrication of prototype hardware. The prototype hardware was then subjected to a series of laboratory stress-strain tests designed to verify the accuracy of the analytical predictions. Each part was instrumented with strain gages and subjected to various static loads. Although this procedure was sufficient to verify the finite element modelling techniques, the static tests could not accurately simulate the inertial loads experienced during gun launch. Therefore, additional prototype hardware was fabricated for use in actual gun-firing tests of nonfunctional structural fuzes. These tests were designed to verify the adequacy of the fuze structural design at a fraction of the cost of testing a complete functional fuze. This was done by replacing all electronic subassemblies with mass mockups to simulate gun-launch inertial loads. In this manner, the structural design adequacy could be verified before the firing of much more expensive functional fuzes. In addition, severe overtests of the structural design were achieved by adding mass at critical points and by using the 155-mm howitzer for substantially higher setback and spin levels. By subjecting the structural fuzes to these overtest levels, the actual structural factor of safety could be determined. This information was then used to refine the structural design to meet the required 1.5 factor of safety and achieve a minimum weight fuze.

This report presents a description and results of the structural gun-firing tests conducted. The mechanical design of the M735 fuze will be discussed briefly, preceding a discussion of the structural test approach that includes the test plan, a detailed description of the structural fuze design, and a description of the test vehicles used. Each design iteration or group will be discussed and test results presented. Finally, a summary will be presented of all structural tests and conclusions drawn from this program.

2. M735 FUZE MECHANICAL DESIGN

The M735 fuze must reliably provide programmed power for all projectile components, accurate height sensing for warhead initiation, and in-flight safety. These requirements are met by a dual-channel fuze system, including target sensor, electronic programmer, and power supply assemblies. The electronic assemblies and components are packaged within the fuze, as shown in figures 2 and 3. The fuze consists of three major assemblies: (1) the nose section, which contains the programmer memory/timing circuits and power supplies; (2) the center assembly, which contains the target sensors and El assemblies; and (3) the rear assembly, which contains the programmer power output and decode circuits.

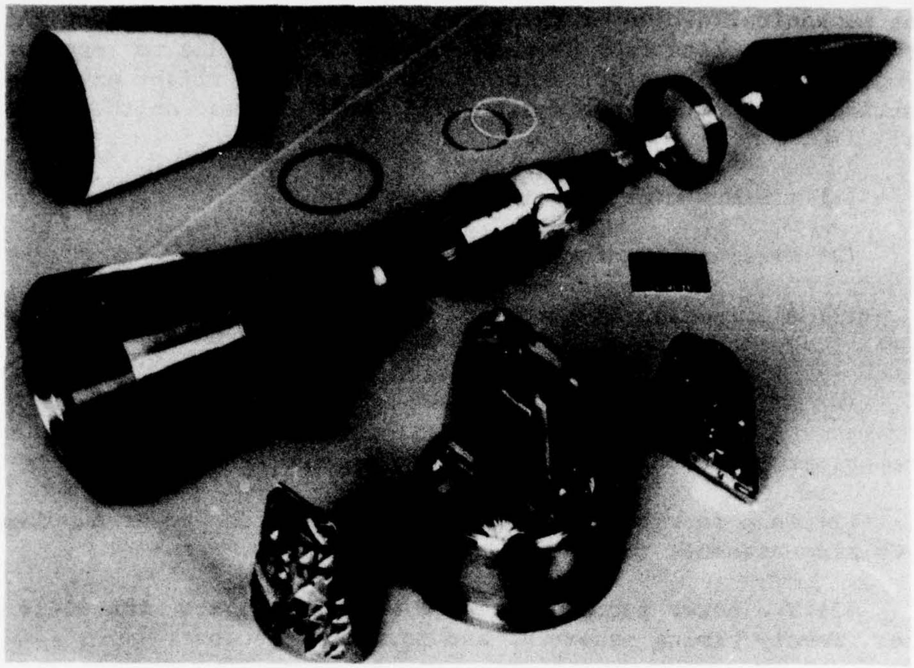

Figure 2. M735 fuze, partially disassembled.

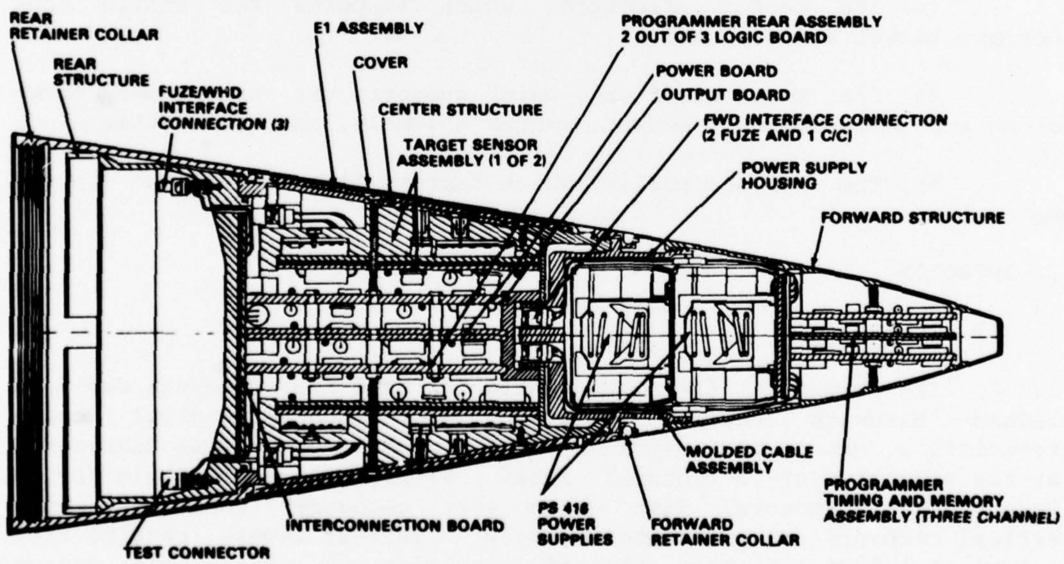

Figure 3. M735 fuze, cross section.

The mechanical design of the fuze is required to protect the fuze electronic assemblies from degradation and failure due to exposure to handling, storage, transportation, and firing and flight environments. In addition, the following design goals were imposed on the mechanical design:

(1) minimum overall weight,

(2) minimum structural volume,

(3) elimination of potting as a means of structural support, and

(4) elimination of wire and cable harnesses.

The primary structural parts of the fuze are as follows.

(1) The forward structure, which clamps the power supplies and memory/timing assembly to the power supply housing,

(2) The power supply housing, which supports the PS416 power supplies, memory/timing assembly, and forward structure,

(3) The forward retainer collar, which fastens the entire nose section to the fuze projectile section,

(4) The center structure, which supports the entire nose section, target sensors, and El,

(5) The rear structure, which supports the programmer power output and decode circuit boards, center assembly, and nose section,

(6) The retainer collar, which fastens the entire fuze to the projectile.

3. APPROACH

3.1 Test Plan

The structural firing test plan for the M735 fuze was based on planned hardware design iterations. For each mechanical design iteration, a group of several sets of structural parts was fabricated for the assembly of structural fuzes. Plans included multiple firing tests of each structural fuze using soft recovery techniques, with vertical recovery and parachute recovery. Overtest levels, ranging from a nominal 1.0 to 1.5, were planned in order to verify the design requirements for a structural safety factor of 1.3 for yield strength and 1.5 for ultimate strength.

3.2 Structural Fuze Design

As stated earlier, the preparation of a structural fuze consisted primarily of replacing all electronic assemblies with mass mockups. Although specific components and subassembly types varied, depending upon the particular test objective, a typical structural test fuze is described below. All circuit board assemblies were replaced with either blank epoxy-fiberglass or multilayer boards loaded with nuts and bolts to simulate the mass of the electronic components. The PS416 power supplies were replaced with inert power supplies; i.e., unfilled or potted ampules. The target sensor assemblies were replaced with either solid metal blocks or actual rf housings loaded with mass mockups in lieu of actual circuits. Cables and connectors were not generally included. Either the El was not included or it was replaced with a blank mockup. All other parts, including the major structural parts, fasteners, and the El cover were actual fuze hardware. Details of the individual structural fuzes are included in the discussion of each test.

3.3 Test Vehicles

Several different vehicles were used in the structural fuze test program. Of prime importance in a program of this nature is recovery of the hardware for post-test inspection and evaluation. Therefore, soft recovery of the structural fuze was mandatory. Two different soft-recovery techniques were used: vertical recovery and parachute recovery.

The simplest test method was vertical recovery at Aberdeen Proving Ground, MD (APG). This method entails firing the projectile at or near vertical, resulting in a nearly vertical base-first descent and impact. The impact area is a plowed field which allows projectile penetration of up to 20 ft (6.1 m). The undesirable but inevitable deceleration experienced by the projectile at impact is in the same direction and is estimated to be of the same order as gun-launch setback acceleration, provided the ground is uniformly soft and without obstructions.

Fuzes were gun fired vertically using both 8-in. and 155-mm modified projectiles. The latter were used when an overtest of setback acceleration was desired, since the 155-mm maximum setback is nearly 1.5 times greater than the 8-in. Because of stability problems encountered in vertical firings on an earlier fuze program, a blunt-nosed aluminum cover was used which attached to the modified 8-in. test projectile, covering the structural fuze. This cover prevented the test projectile from precessing during descent with resulting damage from a sideways ground impact. Also it protected the structural test fuze from damage during the recovery (digging) operation. Due to the smaller diameter of the 155-mm test projectile, it was not possible to use a cover for these

tests. Instead, a flat washer was attached to the fuze nose to eliminate precessing during descent. The mass of the washer added to the inertial loading on the fuze forward structure, thus increasing the overtest level. Both 8-in. and 155-mm vertical recovery test projectiles are shown in figure 4. Appendix A contains a detailed discussion of tests performed to demonstrate the feasibility of the blunt-nosed cover.

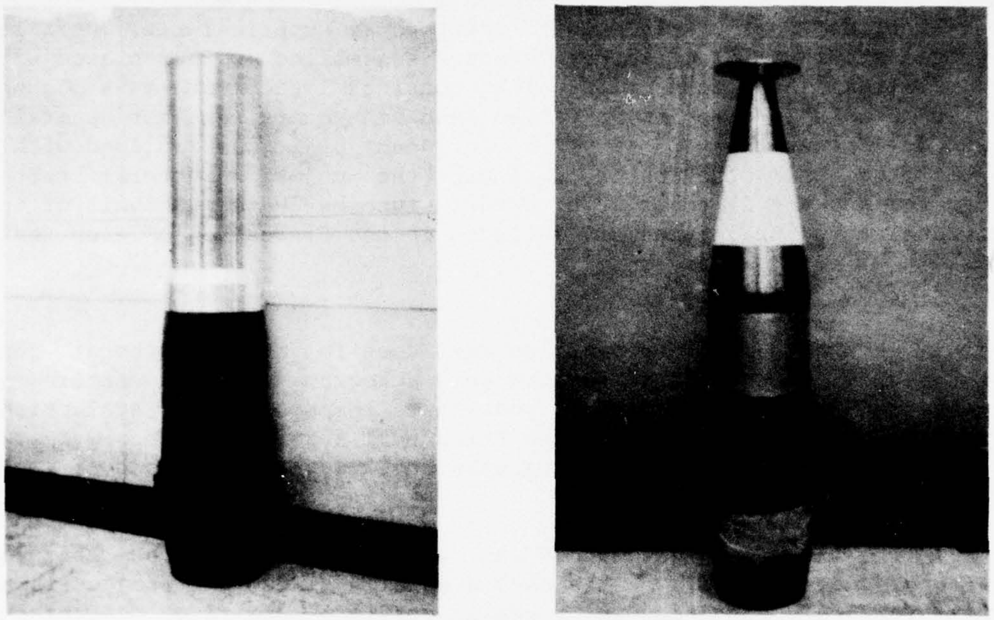

Figure 4. Test rounds: (a) 8-in. test round with bucket and (b) 155-mm test round with spoiler plate.

A more expensive but more realistic method of soft recovery is down-range firing with parachute recovery projectiles developed by the Armament Research and Development Command (ARRADCOM). Both 8-in. (PXR 6200) and 155-mm (PXR 6165) parachute recovery projectiles were used at Yuma Proving Ground, AZ (YPG). Both projectiles function similarly: a preset mechanical time fuze initiates a pyrotechnic chain which ignites a powder charge. The charge expels the projectile base and deploys a parachute at the appropriate point in the trajectory. The parachute slows the payload to a descent velocity of approximately 100 ft/s (~31 m/s). Figures 5 and 6 show a partially disassembled 155-mm parachute recovery vehicle and typical impact of the 8-in. vehicle.

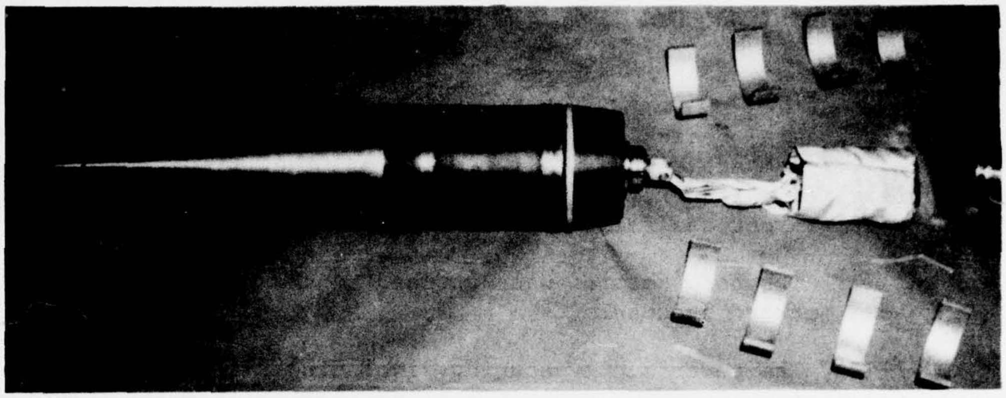

Figure 5. Partially disassembled 155-mm parachute projectile.

Figure 6. Typical impact of 8-in. parachute recovery round.

4. STRUCTURAL FIRING TESTS

4.1 Group 1

The initial design baseline of the M735 fuze, designated here as Group 1, was significantly different from the final fuze design described earlier. In particular, the packaging design of the fuze nose section was different, as follows:

(1) The nose section was attached to the projectile section by a threaded forward structure.

(2) The power supply housing, including PS416 power supplies and a memory/timing assembly, was supported within the forward structure by a retaining nut which allowed free rotation of the power supply housing before its attachment to the projectile section.

(3) The memory/timing assembly consisted of three printed-circuit boards mounted perpendicular to the fuze axis. The boards were potted as an assembly and supported by the top power supply.

(4) A small cap was attached to the front end of the forward structure.

(5) The power supply housing potting extended above the forward surface of the housing to form a cylinder around the forward power supply.

4.1.1 Description

One structural test fuze was assembled for gun-firing tests to verify the adequacy of the Group 1 structural design. The structural fuze is depicted in figure 7. All structural parts of the fuze were included in the assembly; electronic components and subassemblies were replaced with mockup parts. In particular, the target sensors were replaced with solid aluminum blocks, the programmer and interconnection boards with blank epoxy-fiberglass boards, the memory/timing assembly with a solid aluminum disk, and the power supplies with inert PS416 assemblies. The El, connectors, and cable harnesses were not included. All mockup part weights were equal to, or slightly greater than, actual part weights. A list of part weights is included in table 1.

The structural fuze was gun fired twice, vertically at APG and down-range at YPG, with parachute recovery. In the first test, the fuze was fired from the 8-in. M2A1E1 gun, with an M2 propelling charge, in Zone 7, at ambient temperature. Unfortunately, both chamber pressure gauges were expelled. It was therefore assumed that the chamber pressure equalled that of the previous spotter round, 32,500 psi, with a

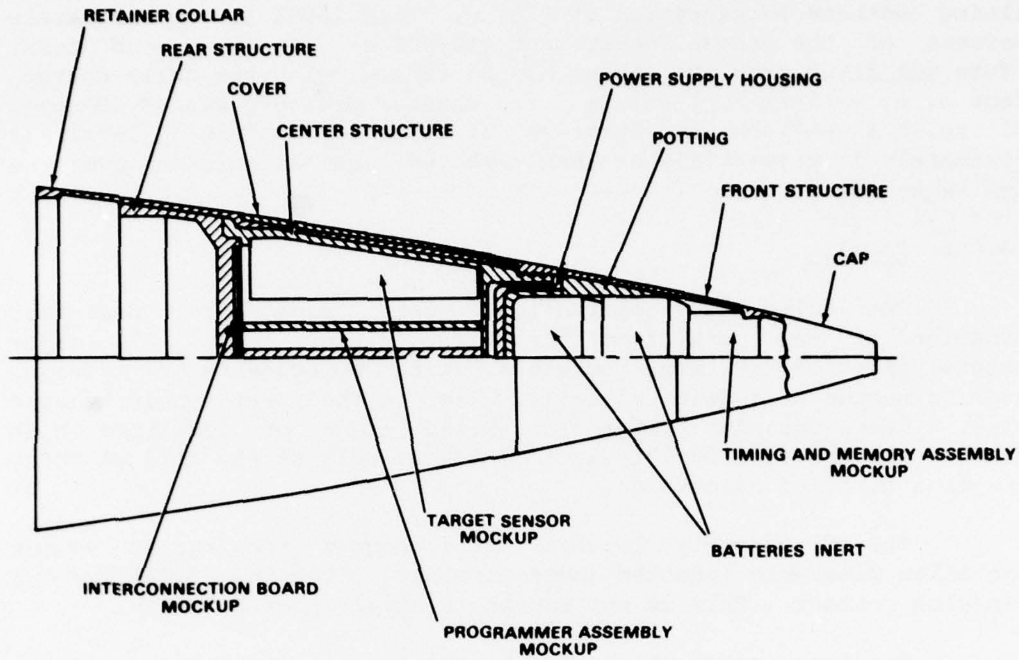

Figure 7. Structural mockup fuze, Group 1.

TABLE 1. COMPONENT WEIGHTS, GROUP 1
(lb × 0.453592 = kg)

Component	Weight (lb)
Retainer collar	1.52
Forward structure	0.53
Retaining nut	0.04
Memory/timing mockup	0.25
Power supplies (2)	1.26
Forward assembly potting	0.15
Power supply housing	0.56
Center structure	1.60
Target sensor mockups (2)	2.23
Connector plates (3)	0.09
Programmer support brackets (2)	0.02
Rear structure	1.59
Interconnection assembly mockup	0.14
Programmer assembly mockup	0.73
Cap	0.12
Cover	0.41
TOTAL	11.24

resulting setback acceleration of 8700 g. This level is approximately 80 percent of the design requirement (10,400 g). In the second test, the fuze was fired from the 155-mm M126E1 cannon, with the XM119 charge, in Zone 8, at ambient temperature. The chamber pressure was 48,000 psi, resulting in a setback acceleration of 15,000 g. This g level is approximately 15 percent higher than expected and 45 percent over the design requirement.

4.1.2 Results

The following observations were made after post-test examination of the fuze from the first firing test. All major structural parts of the fuze survived, with no evidence of yielding. However, a number of fasteners failed, as did the power supply housing potting. The programmer boards also showed signs of localized high stresses. The observed individual failures as well as the failure modes follow in a detailed discussion.

The rf assembly keyways which engage the target sensor antirotation pins were indented approximately 0.001 in. (0.025 mm) due to pin/slot contact. This is not enough to impair part function.

The four screws which attach the target sensor assemblies to the center structure failed in shear. This failure was attributed to the potential differential axial deflection of the rf housings and center structure. In particular, the thin-walled center structure is not nearly as stiff as the rf housings in the axial direction. In addition, this structure must support a much larger inertial load, including the total mass of the nose section. As a result, the center structure axial strain rate is larger than that of the rf housings, thereby causing relative motion of the center structure with respect to the rf housings at gun launch. If the rf mounting screw clearance holes in the center structure are not large enough to accommodate this motion, the screw can fail.

The set screws which provide lateral support to the center of the programmer assembly failed (one was fractured and one was severely bent). This failure was attributed to the potential differential deflection of the rf housings and rear assembly, in particular the rear structure. Since the rear structure is inherently more compliant and more heavily loaded than the rf housings, the interface between the set screw and programmer assembly must be able to accommodate relative axial motion. If this interface does not provide a relatively smooth surface, the set screw can be pulled down by the rear assembly, thus resulting in screw failure. In this instance the set screws were prevented from moving by the protrusion of the tie bolt on the programmer assembly.

The forward assembly potting fractured at the forward lip of the power supply housing. This failure was apparently caused by the lack of adequate structural support for that portion of the potting which extended above the housing lip.

The two tie bolts which fasten the programmer assembly to the mounting blocks failed: both were severely bent and one was fractured. Due to the nature of the failure, and the fact that these bolts are not under load during setback acceleration, the failure was attributed to compression release acceleration. This acceleration results when the projectile's axial acceleration is suddenly unloaded at muzzle exit. This sudden load release produces a rebound effect which essentially results in a tensile wave traveling through the projectile. In this instance, the programmer boards are driven forward with respect to the rear structure. Relative motion of the board with respect to the rear structure is restrained by the tie bolts. In addition, the rear structure rebounds forward at its center, resulting in a slap to the bottom of the programmer boards which also loads the tie bolts. It was apparent from this failure that the tie bolts were not adequate.

The programmer boards exhibited localized delamination and thread engraving on the upper surface of the mounting holes. This damage also appeared to have been caused by compression release acceleration. The programmer boards also exhibited very slight localized delamination in the foot area. This localized failure was caused by setback acceleration loading, which produces highly localized stress in this area of the board. In particular, the programmer board support in this area was marginal due to cut-outs of the interconnect board in the mounting block area.

As a result of the first test observations, a number of changes were incorporated in the structural fuze prior to the second firing test:

- The center structure/rf mounting screw clearance holes were elongated to allow for the differential axial deflections of the rf housings and center structure, and thereby prevent shearing of the mounting screws.

- The programmer center tie bolt was replaced with a threaded stud and nuts. The threaded stud length was such that it did not protrude beyond the outer surface of the nuts. The nuts provide a relatively smooth flat surface for the lateral support set screws, thus allowing axial movement of the programmer assembly nut with respect to the stud and preventing set screw failure.

- The power supply housing potting extension above the forward lip was eliminated to prevent potting failure.

● The programmer/mounting block tie bolts were replaced with high strength studs to prevent stud failure and programmer board delamination/engraving.

● A larger full diameter interconnection board was used which provided full edge-to-edge support of the programmer boards to minimize delamination in the foot area of the boards.

The following observations were made after post-test examination of the fuze from the second firing test. All major structural parts of the fuze survived with no evidence of yielding. However, the rf assembly keyways were indented approximately 0.002 in. (0.050 mm) and the programmer lateral support set screws were bent slightly. Neither of these was severe enough to impair part function. The cover wire retainer failed in shear. This part was a small diameter wire loop which was mounted in a groove inside the center structure. The two ends of the wire extended through holes in the center structure and engaged similar holes in the cover. The purpose of the retainer was to retain the cover to the fuze during handling (prior to assembly of the fuze nose section) and prevent angular rotation of the cover during flight. It was apparent that the retainer was inadequate to prevent cover rotation during projectile angular acceleration. No other damage was evident to any fuze part.

4.1.3 Conclusions

The following conclusions were based on the results of the Group 1 structural fuze firing tests.

All major structural parts of the fuze survived both tests with no evidence of yielding, and therefore were structurally adequate. In fact, the second test results indicated that a factor of safety of 1.45 had been achieved.

Numerous design modifications were made as a result of failures which occurred in the first test. Since none of these failures occurred in the second test, it can be concluded that these modifications were successful and should be incorporated as design changes.

The cover wire retainer was the only significant part failure to occur on the second test. It was therefore recommended that this part be replaced by an O-ring and high strength pins.

It was also recommended that future structural mockup fuzes include multilayer programmer boards in order to better determine the adequacy of the programmer board support.

4.2 Group 4A/B

The next fuze design iteration, designated Group 4A/B, was very similar to the previously described Group 1 design. Several minor changes were incorporated in addition to those resulting from the Group 1 test observations.

4.2.1 Description

Two Group 4A/B structural mockup fuzes were assembled, including all critical structural parts. Those components not critical to the structural design were replaced with less expensive mockups. Figure 8 shows a cross section of the Group 4A/B structural fuze.

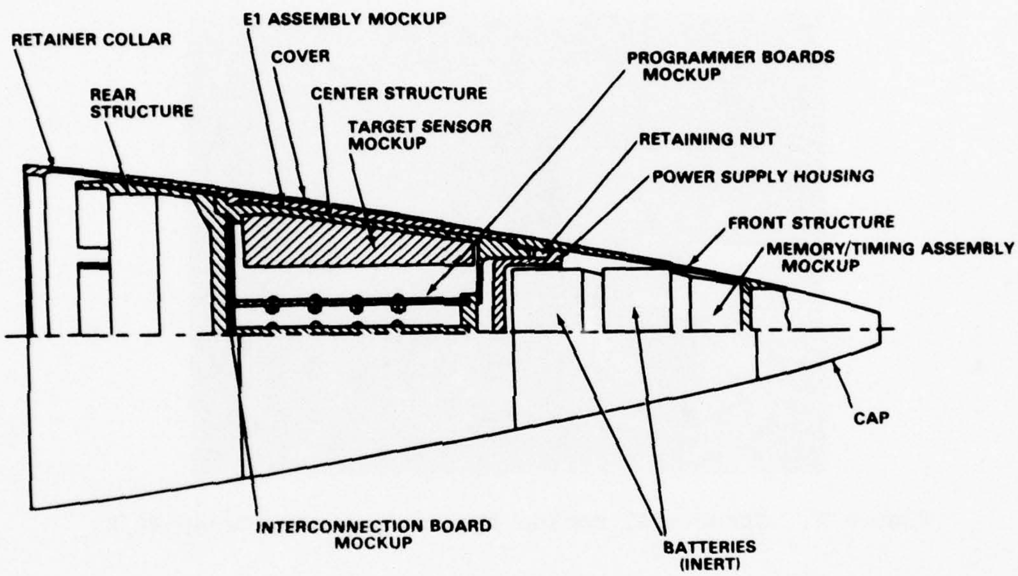

Figure 8. Structural mockup fuze, Group 4A/B.

Referring to figure 8, the test specimens were assembled with the following fuze parts: cap, forward structure, power supply housing (with potting), retaining nut, center structure, retainer collar, rear structure, cover, and miscellaneous brackets and fasteners. The PS416 batteries were replaced with inert batteries (electrolyte not included). The memory/timing assembly was replaced with a solid metal disk. The mass of this component was adjusted for different load factors by using different density materials. The E1 assembly was replaced with a blank mockup bonded to the center structure. The target sensor assemblies were replaced with blank rf housings. Brass plates were attached to the

housings to adjust the mass of these assemblies for different load factors. The interconnect assembly consisted of an insulator, spacer, and bare multilayer interconnect board. The programmer assembly consisted of bare multilayer programmer boards and all associated mounting hardware. Nuts and bolts were attached to the boards to adjust the mass of this assembly for various load factors. Connectors and wire harnesses were not included in any of the above assemblies. A set of structural fuze components is shown in figure 9.

A series of three vertical-recovery gun-firing tests was conducted at APG. The fuzes were fired from the 8-in. gun in the first two tests, and from the 155-mm howitzer in the third test. Blunt-nosed covers were used for the 8-in. tests, and spoiler plates were used for the 155-mm tests.

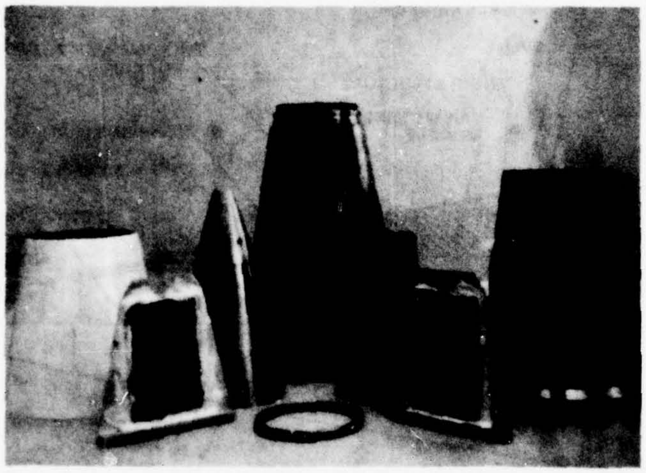

Figure 9. Structural mockup fuze components, Group 4A/B.

4.2.2 Results

Table 2 lists the structural mockup fuze component weights for each gun-firing test compared to the actual fuze weights. The setback load factors at critical locations of the fuze structural parts are included in table 3. The computation of these load factors was based on the mockup fuze component weights and setback acceleration achieved for each test, versus the actual fuze weights and the maximum design setback acceleration level (10,400 g). A summary of the gun-firing test conditions and post-firing test specimen observations is presented in table 4. A detailed discussion of each gun-firing test follows.

TABLE 2. COMPONENT WEIGHTS, GROUP 4A/B
(lb × 0.453592 = kg)

Component	Actual weight (lb)	Structural mockup weight (lb)		
		T-I	T-II	T-III
Cap	0.12	0.12	0.73	0.57
Forward structure	0.45	0.45	0.45	0.45
Retaining nut	0.04	0.04	0.04	0.04
Power supply housing assembly	0.61	0.59	0.59	0.59
Power supply assembly	1.45	1.27	1.27	1.27
Memory/timing assembly	0.20	0.20	0.65	0.65
Cover	0.42	0.42	0.42	0.42
Retainer collar	1.06	0.88	0.88	0.88
Center structure	1.31	1.31	1.31	1.31
EI	0.52	0.52	0.52	0.52
Target sensory assembly (2)	1.85	1.78	2.27	2.27
Rear structure	1.97	1.97	1.97	1.97
Interconnect assembly	0.29	0.22	0.22	0.22
Programmer A	0.21	0.21	0.30	0.30
Programmer B	0.26	0.22	0.30	0.30
Programmer C	0.24	0.20	0.31	0.31
Miscellaneous parts	0.49	0.49	0.49	0.49
TOTAL	11.49	10.91	12.72	12.56

TABLE 3. LOAD FACTORS, GROUP 4A/B

Location	Test number		
	T-I	T-II	T-III
Power supply housing base	0.91	1.16	1.38
Retaining nut	0.92	1.12	1.33
Center structure forward end	0.94	1.31	1.49
Center structure shelf	0.97	1.24	1.48
Rear structure rim	0.97	1.21	1.40
Rear structure programmer	0.86	1.14	1.36

TABLE 4. TEST RESULTS SUMMARY (lb × 0.453592 = kg)

Test	Date	Projectile	Test round weight (lb)	Weapon	Propellant	Setback (g)	Test specimen observations
T-I	2 July 1975	MOD M106 with bucket	183	8-in., XM201 tube	XM188, Zone 9, +145 F	10,500	T-I-1: Severe ballot and/or side impact; programmer mounting blocks failed T-I-2: No damage
T-II	20 August 1975	MOD M106 with bucket	159	8-in., XM201 tube	XM188, Zone 9, +135 F	10,500	T-II-1: Programmer mounting screws yielded T-II-2: No damage
T-III	16 September 1975	MOD M107 with spoiler	87	155-mm, M1A2 tube	M4A2, Zone 7, +145 F	12,500	T-III-1: Target sensor antirotation pins loose T-III-2: Cover failed

Both structural mockup fuzes were assembled as previously described for the first gun-firing test. The mockup components were designed to match the actual fuze component masses as nearly as possible. The test specimens were mounted to 8-in. test rounds and gun fired at 10,500 g. Both test rounds were successfully recovered and delivered to Harry Diamond Laboratories (HDL) for post-firing disassembly and evaluation.

The first test round apparently experienced severe transverse loadings. The bucket was noticeably cocked to one side and difficult to remove. Severe rifling engravement was observed on one side of the projectile bourrelet. Paint wear was also more predominant on one side of the projectile. A possible sequence of events resulting in damage of this nature is as follows. The projectile may have experienced severe ballotting impacts in the gun tube, resulting in damage to and cocking of the bucket. The resultant aerodynamic configuration and center of gravity offset may have caused the round to precess during descent. This precession could then have resulted in an off-center impact with additional transverse loads and the observed abnormal paint wear. Therefore, the test round may have experienced high transverse loadings at both launch and impact. It should be noted that the bourrelet engravements were substantially more severe than those observed on previous test rounds.

The structural mockup fuze was then disassembled and the following damage was noted. The programmer mounting-block screw threads failed in shear. There were also areas of slight edge delamination at the top of the programmer boards. These areas were more pronounced on one side of the programmer board edges. Apparently, the mounting-block failure allowed the programmer assembly to impact the connector plates, resulting in the board edge delamination. The more severe failure on one side of the boards indicated that the programmer assembly may have rotated, or cocked to one side, before impacting the connector plates. This, along with the previously described test round damage, suggests that the mounting-block failure may have resulted from abnormally high transverse loadings.

The second test round was disassembled, and no damage to the test vehicle was observed. The structural mockup fuze parts exhibited no signs of damage or yielding.

The structural mockup fuzes were then reassembled for another gun-firing test. It was desired for this test to overload by mass several critical areas of the fuze structure by approximately 20 percent. Therefore, the memory/timing, target sensor, and programmer assembly mockup masses were adjusted accordingly, and the cap was replaced with a solid brass mockup.

Before the test specimen was assembled, both fuze rear structures were modified to conform to an interface change between the fuze and warhead electrical system, effective for Group 4C/D fuzes. This modification consisted of removing material from the internal contour of the rear structure. It was highly desirable to include this change in this gun-firing test, since it slightly reduced the strength and stiffness of the rear structure.

In addition, rear assembly shims were included in one of the structural mockup fuzes to evaluate their effect on the programmer assembly support. It was proposed that, by sandwiching shims of various sizes and thicknesses between the rear structure and programmer assembly, the programmer assembly support could be spread over a larger area. This, in turn, should reduce the peak stresses in the programmer boards. Figure 10 shows the shim configuration included in this test specimen. The rear assembly deflected shapes for a 10,400-g setback loading are also shown in figure 10 for configurations with and without shims.

The test specimens were mounted to 8-in. test rounds and gun fired at 10,500 g. Both test rounds were successfully recovered and delivered to HDL for disassembly and evaluation.

The first test round was disassembled, and no damage to the test vehicle was observed. Upon disassembly of the fuze, it was observed that the programmer assembly was not seated on the interconnect boards. The programmer mounting screws were loose, and apparently had yielded slightly. No other fuze parts exhibited signs of damage or yielding.

The second test round and structural mockup fuzes were disassembled. There was no damage or yielding to any fuze part. Markings found on both the rear structure and interconnect boards along the shim edges indicated that the programmer assembly support reaction was transmitted to the rear structure as had been predicted.

The structural mockup fuzes were reassembled for a final gun-firing test. For this test, a 50-percent overtest of the critical structural parts was desired. This could be achieved by a combination of a 20-percent mass overload and a 25-percent setback acceleration overtest by firing the test specimens from the 155-mm howitzer. The fuze mockup component masses were therefore adjusted as in the previous test. However, in this case the cap was replaced with a spoiler plate assembly.

The rear structures of the fuze, as previously modified to conform to the Group 4C/D design, were again used. Also, the rear assembly shims were again included in one of the structural mockup fuzes.

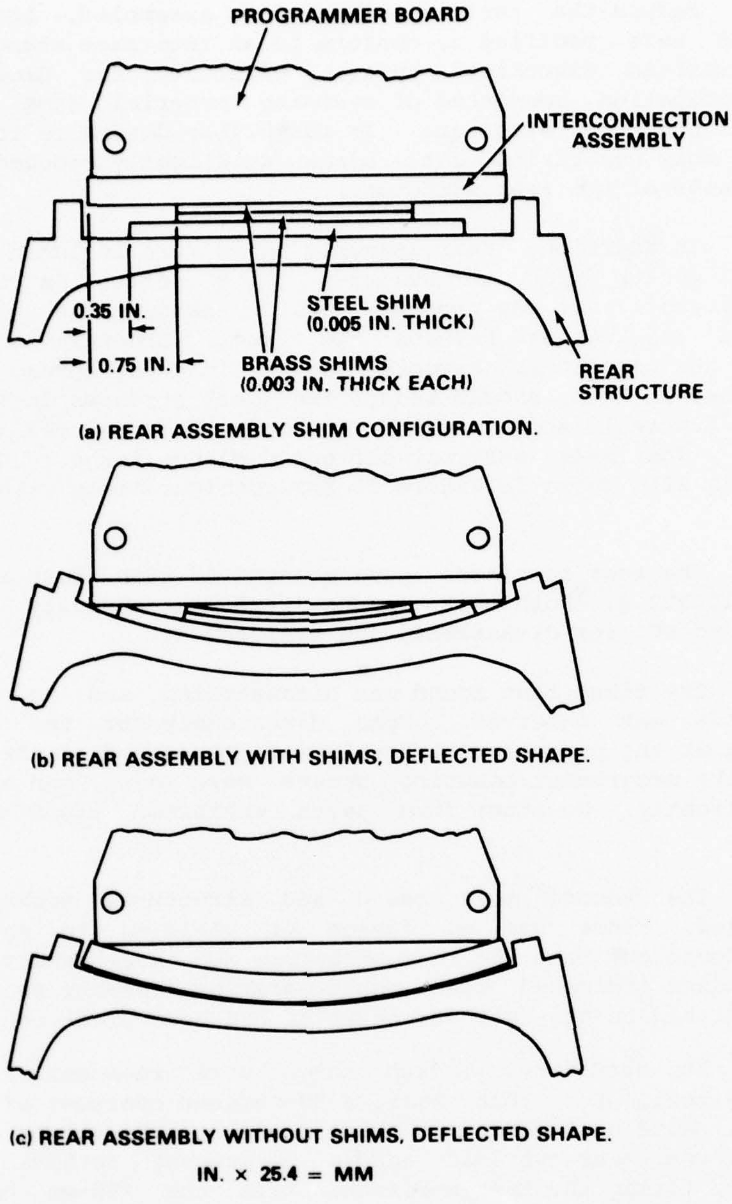

Figure 10. Rear assembly with and without shims: (a) rear assembly shim configuration, (b) rear assembly with shims, deflected shape, and (c) rear assembly without shims, deflected shape.

In addition, the epoxy-fiberglass cover was replaced with a new lightweight cover. This cover differed from the previous gun-fired covers. The wall thickness was reduced for weight savings; the cover was fabricated with random glass fibers in a compression mold rather than laid-up with glass cloth. The new cover design was included in this assembly to evaluate its structural adequacy. There were doubts concerning the cover's adequacy, particularly because small cracks were observed on this and other similar covers before the gun-firing test.

The structural mockup fuzes were mounted to 155-mm test rounds and gun fired at 12,500 g. This was equivalent to a 20-percent setback acceleration overtest. A setback acceleration of 13,000 g was required to produce the desired 25-percent overtest. Both test rounds were successfully recovered and delivered to HDL for evaluation.

There was no apparent damage to the first test round. After disassembly of the structural mockup fuze, both target sensor antirotation pins were found loose in the center assembly. The repeated gun-firing tests may have resulted in a slight elongation of the pin holes in the center structure, causing the pins to fall out. However, there was no evidence of any target sensor rotation. There were no signs of damage or yielding to any fuze part.

The second test round also was undamaged. However, the lightweight cover failed at gun firing. A number of small pieces of the cover were recovered at the gun site. Figure 11 shows the remains of the cover. No other fuze component was damaged, and none of the structural parts yielded.

Figure 11. Experimental lightweight cover after firing test.

4.2.3 Conclusions

As a result of these gun-firing tests, the following conclusions and recommendations were made.

The programmer mounting screws and aluminum mounting blocks were not structurally adequate. Larger diameter screws and high strength mounting blocks (steel or titanium) should be used.

The target sensor antirotation pin failure was unusual, and may have occurred due to the number of repeated tests. Since the target sensors did not rotate with respect to this center structure, it can be concluded that the part function was not impaired.

The new compression-molded cover was structurally inadequate. The cover design should be changed back to a laid-up glass cloth of a thinner design. A cover of this type with the reduced wall thickness should provide adequate strength with similar weight savings.

The rear assembly shims appeared to spread the programmer assembly support as predicted. However, since no programmer board failure occurred on any of these tests, it is not possible to determine their effect on reducing the programmer board peak stress. Further testing is needed before a design change can be recommended.

The Group 4A/B major structural parts and the Group 4C/D rear structure exceed the requirement for a 1.3 factor of safety for yield strength. Additional gun-firing tests are necessary to demonstrate a 1.5 factor of safety for ultimate strength.

4.3 Group 4C/D

The next fuze design iteration, designated Group 4C/D, was very similar to the Group 4A/B design. Several changes were incorporated as a result of previous gun-firing tests in addition to the redesigned rear structure described previously.

4.3.1 Description

Three structural fuzes were assembled, all with different electrical subassembly mockup weights. One represented the weight of a 4C design fuze (1.00 overload); the other two represented mass overloads of 1.2 and 1.4.

Certain assembly and part weights varied from the weight factor of the fuzes for modelling convenience. Several subassembly mockups from previous tests were reused when a combination was needed to produce one weight factor. This reduced the number of new parts that

had to be fabricated. The actual fuze parts used were the forward structure, power supply housing, retainer nut, center structure, retainer collar, rear structure, and fasteners. The programmer mounting blocks were changed to stainless steel, and the mounting screw diameter was increased as a result of the previous tests. In addition, the mounting hole location was moved to distribute the load more evenly across the mounting-block stud.

Three El covers, each of different material, were tested on the structural fuzes. The 1.00 fuze cover was compression-molded epoxy, filled with glass fibers of random lengths; the 1.20 fuze cover was a laid-up glass cloth epoxy; and the 1.40 fuze cover was a laid-up glass-filled phenolic-silicone cloth. A 5-in. (127-mm) spoiler plate was used in place of the cap to prevent precessing during base first descent. The El assembly on all center structures was replaced with a blank mockup. The PS416 power supply assemblies and memory/timing assemblies were replaced with machined and molded parts, respectively. The weights of these assemblies were varied by using a combination of different materials. The target sensor assemblies were replaced with aluminum rf housings. Metal plates were both screwed and bonded with epoxy to these housings for weight adjustment. The interconnect assembly was composed of an insulator, a spacer, a bare multilayer interconnect board, and the shims. The programmer assembly consisted of bare multilayer boards with nuts and bolts attached to vary the weights.

Two gun-firing tests were conducted. The purpose of these tests was to verify the design factor of safety and determine the feasibility of planned redesign efforts to reduce overall fuze weight. In both tests, the fuzes were fired vertically at APG using the 155-mm test projectile.

4.3.2 Results

Table 5 lists the fuze parts and total weights fired in the first test. The 1.00 structural fuze was lost during the flight. It appeared to have gone unstable and landed in the river. Attempts to recover this round were unsuccessful. Setback accelerations of 15,300 and 15,200 g were achieved for the 1.20 and 1.40 fuzes, respectively. The percentages of the actual load factors on the structural parts are shown in table 6. The two rounds were successfully recovered and delivered to HDL for disassembly and inspection.

On disassembly, it was found that the El cover on the 1.20 fuze had rotated approximately 170 deg. The pins were bent on the center structure that positioned the El cover. The cover was also cracked at the initial pin locations. No other damage occurred during firing or impact.

TABLE 5. TEST I--PART WEIGHTS (lb × 0.453592 = kg)

Part	Fuze (weight in lb)			
	4C Design	~1.00	~1.20	~1.40
Memory/timing assembly	0.20	0.17	0.61	0.17
PS416 assemblies	1.44	0.98	1.32	2.46
Power supply housing	0.63	0.60	0.59	0.59
Retainer nut	0.06	0.06	0.06	0.06
Spoiler plate assembly/cap	0.12	0.57	0.57	0.57
Forward structure	0.46	0.46	0.46	0.46
T/S 1 assembly	0.90	0.79	1.03	1.21
T/S 2 assembly	0.90	0.79	1.03	1.21
Programmer assembly	0.81	0.82	0.98	1.18
Connector plate	0.10	0.08	0.08	0.08
Collar	0.98	0.87	0.87	0.87
Center structure	1.31	1.31	1.31	1.31
EI assembly	0.55	0.58	0.57	0.55
Cover	0.40	0.25	0.25	0.24
Interconnection assembly	0.29	0.23	0.23	0.23
Rear structure	1.94	1.94	1.94	1.94
Total fuze weight[a]	11.35	10.53	11.93	13.13

[a]*Includes miscellaneous parts weight*

TABLE 6. TEST I--PERCENT LOAD FACTOR

Location	Load factor	
	Fuze	
	~1.2	~1.4
Power supply housing base	1.69	2.23
Retaining nut	1.63	2.07
Center structure forward end	1.82	2.16
Rear structure rim	1.69	1.90
Programmer assembly base	1.78	2.13

The 1.40 fuze had the same failures as the 1.20 fuze. However, the El cover rotated only 20 deg. In addition, some of the epoxy had broken loose from the rf housing, but the screws held.

Since both fuzes survived this extreme overtest with no structural yielding, a redesign was undertaken to reduce the overall fuze weight. Another vertical recovery test was scheduled, incorporating several modifications to the fuzes. The rear structure had 0.020 in. (0.51 mm) removed from all interior surfaces to provide a weight reduction. This modification should affect only the loading characteristics of the programmer boards. In addition, it was decided to eliminate the center structure pins that hold the El cover in place and allow the cover to rotate during flight.

For this second test the 1.40 fuze mockup assemblies were changed to incorporate the anticipated actual weights of the Group 5A fuze. The 1.20 fuze incorporated the same mockup assemblies, but when compared to the reduced weights of the Group 5A fuzes, the weight overload increased to 1.23. Both fuzes were assembled using the same structural parts as before. This time the 1.00 fuze had the previously cracked phenolic-silicone El cover and the 1.25 fuze had the cracked epoxy cloth cover.

Table 7 lists the parts and total fuze weights for this second test. The 1.00 and 1.25 fuzes experienced setback accelerations of 13,750 and 13,150 g, respectively. Table 8 shows the percentages of the actual fuze load factors on the structural parts. Both rounds made an abnormal sound on firing, as compared to the similitude spotter. This could possibly be due to yawing, which would account for the short time of flight. Both fuzes were in the air appproximately 10 s less than the spotter round. Both fuzes were recovered and brought back to the laboratory for disassembly and inspection. The 1.25 fuze was badly damaged in the recovery process. There did not appear to be any failures due to gun-firing conditions. The 1.00 fuze survived, undamaged, both the gun-firing and recovery procedures.

Due to the abnormal sound heard on firing the rounds, the 1.00 fuze and the spotter were reassembled and sent to APG for dynamic balance tests. A comparison of the test results showed that the 1.00 fuze projectile had a larger dynamic imbalance than the similitude spotter. This may explain the difference in the flight characteristics of the rounds.

TABLE 7. TEST II--PART WEIGHTS (lb × 0.453592 = kg)

Part	Fuze (weight in lb)		
	5A Design	~1.00	~1.25
Memory/timing assembly	0.24	0.17	0.61
PS416 assemblies	1.23	1.02	1.32
Power supply housing	0.57	0.59	0.59
Forward collar/retainer nut	0.17	0.06	0.06
Spoiler plate assembly	N/A	0.55	0.55
Forward structure	0.35	0.45	0.46
T/S 1 assembly	0.85	0.79	1.03
T/S 2 assembly	0.85	0.79	1.03
Programmer assembly	0.75	0.83	0.98
Connector plate	0.10	0.08	0.08
Collar	0.96	0.87	0.87
Center structure	1.20	1.31	1.31
EI assembly	0.55	0.55	0.57
Cover	0.25	0.24	0.25
Interconnection assembly	0.30	0.23	0.23
Rear structure	1.77	1.81	1.80
Total fuze weight[a]	10.50	10.33	11.73

[a] *Includes miscellaneous parts weight*

TABLE 8. TEST II--PERCENT LOAD FACTOR

Location	Load factor	
	Fuze	
	~1.00	~1.25
Power supply housing base	1.11	1.42
Retaining nut	1.15	1.56
Center structure forward end	1.46	1.77
Rear structure rim	1.37	1.73
Programmer assembly base	1.46	1.65

4.3.3 Conclusions

Neither of the structural tests produced a failure in any of the major structural parts. This indicated that a redesign to reduce weight is possible since the required factor of safety has been exceeded in all other parts. Some parts demonstrated a factor of safety of 2.0. The modified rear structure did not create any problems in the structural fuze, suggesting that at least 0.020 in. (0.51 mm) may be removed from all sides of this part to reduce fuze weight.

The shims between the rear structure and programmer assembly will be incorporated into the design since they apparently distribute the programmer load with no damage to the assembly. However, in later Group 4C/D electronic fuze vertical recovery tests the programmer mounting-block studs were found to be inadequate. Higher strength studs will have to be investigated in the next group of structural fuzes.

Both the phenolic-silicone and epoxy-fiberglass El covers survived gun firing on the last test. Therefore, structurally, the pins positioning the cover were not needed. Future fuzes will use the epoxy-fiberglass covers, with cost the deciding factor since both are structurally adequate.

4.4 Group 5A/B

The Group 5A fuze design incorporated some major design changes. These included substantial weight reductions in the rear and center structures in addition to a completely redesigned forward assembly. The Group 5A design was the initial fuze design which reflected the configuration described earlier and shown in figures 1, 2, and 3. The Group 5B configuration was essentially identical to 5A, with the exception of a number of minor dimensional changes and the addition of a 0.85-in. long by 0.30-in. high cut-out of the memory/timing boards for inclusion of additional electronic components. Both configurations were subjected to an extensive series of structural firing tests.

4.4.1 Description

Three structural fuzes were assembled, all having the same internal load factors. Figure 12 shows the location of the loads of interest, and table 9 gives the design weights at these locations. The mockup assemblies were designed to 1.25 times the weight of the electronic subassemblies they were replacing. However, when combining subassemblies in the fuze, load factors vary. The actual fuze parts used were the forward structure, forward retainer collar, a potted power supply housing without the wiring harness, center structure, rf chassis, rear structure, retainer collar, and all assembly fasteners. A weight

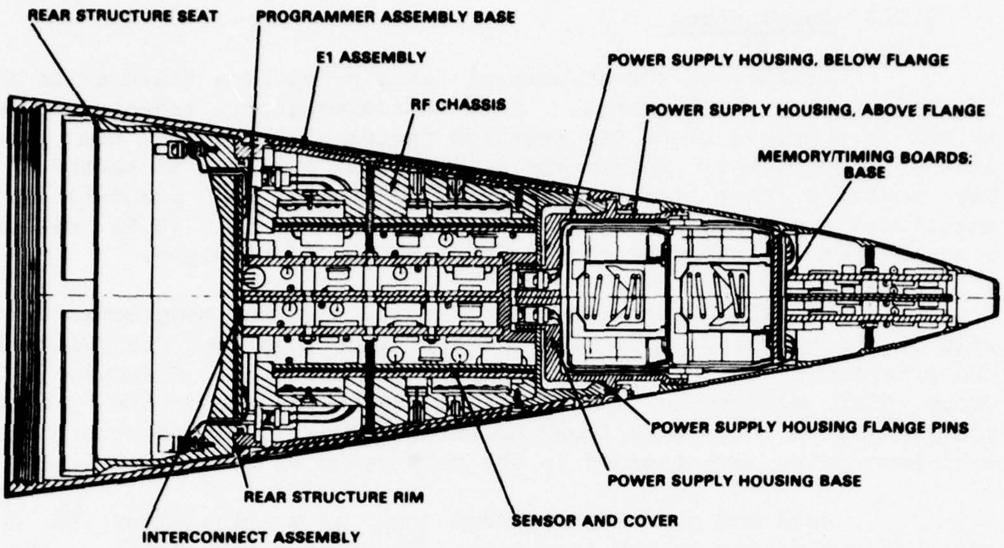

Figure 12. M735 load locations.

TABLE 9. GROUP 5A/B FUZE LOCATIONS AND DESIGN LOADS
(lb × 0.453592 = kg)

Location	Load (lb)
Memory/timing boards, base	0.17
Power supply housing wall, above flange	0.46
Power supply housing base	1.80
Power supply housing wall, below flange	1.96
Power supply housing flange	2.58
Power supply housing flange pins, polar moment	2.5 in.-lb
Sensor load and cover	0.30
RF chassis, cover	0.57
Programmer assembly base	0.73
Rear structure rim	6.27
Rear structure, self load	0.75
Reaction at rear structure seat	9.36

was bolted to the nose of the forward structure to produce an overload on the fuze outer shell. The E1 assemblies were replaced with modified blank mockups. Copper tape was wrapped on these to bring them up to actual weight. The vertical memory/timing boards were weighted with brass plates mounted with nuts and bolts. The interconnect and sensor spacers and insulators were replaced with brass plates. The programmer boards were weighted with nuts and bolts. All electronic boards in the first test were solid G-10 fiberglass boards. These were replaced with actual multilayer circuit boards in the last two tests. The PS416 assembly was replaced with an inert power supply and a machined steel mockup. The rf chassis was weighted with both internal and external brass plates. Programmer mounting-block studs of varying diameters and materials were used in these tests in order to find a stud of adequate strength. Figure 13 shows a Group 5 structural fuze and components.

Three gun-firing tests were conducted of the Group 5A structural fuzes. The first two tests were vertical recovery firings at APG using 8-in. test projectiles. These were fired from the XM201 cannon with the Zone 9, XM188 charge heated to 135 F. These tests produced the design setback acceleration (10,400 g). The third test was conducted at YPG using the PXR 6165 parachute recovery vehicle fired down-range. These were fired from the M1A2 cannon using M4A2 Zone 7 charges heated to 145 F. These conditions provided a combined setback acceleration and weight overtest of 1.5.

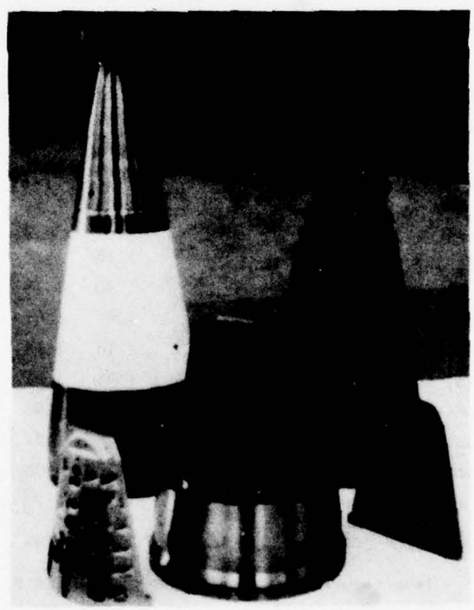

Figure 13. Group 5 structural fuze.

Four Group 5B structural fuzes were assembled using the same weighted mockup assemblies previously used in the 5A tests. A series of three gun-firing tests was also conducted for the 5B design. In the first test the structural fuzes were gun fired vertically on 8-in. projectiles at APG using the XM201 cannon and XM188 Zone 9 charge, heated to 135 F. The second and third tests were conducted at YPG using the PXR 6165 parachute recovery projectile.

4.4.2 Results

In the first 5A gun-firing test, each fuze was assembled with one regular 4-40 UNC programmer mounting-block stud and a specially heat-treated 17-4 PH stainless steel stud. The heat treatment consisted of subjecting the stud to 975 F for 4 hr, followed by air cooling. All electronic boards were replaced with solid fiberglass boards. To create an overtest on the outer shell of the fuze, a 5-in. diam spoiler plate was mounted to the nose.

The fuzes were fired vertically and recovered at APG. Fuzes 1 and 3 were temperature conditioned to -35 F and fuze 2 was conditioned to +135 F. The setback accelerations obtained were 10,400 g for fuzes 1 and 3 and 10,500 g for fuze 2. Table 10 shows the resulting load factors.

TABLE 10. TEST I--PERCENTAGE OVERTEST BY WEIGHT AND FIRING CONDITIONS[a]
(18 March 1976)

Location	Fuze no. 1	2	3
Memory/timing boards, base	1.71	1.73	1.65
Power supply housing wall, above flange	2.30	2.32	2.30
Power supply housing base	1.28	1.29	1.28
Power supply housing wall, below flange	1.18	1.19	1.18
Power supply housing flange	1.38	1.39	1.38
Power supply housing flange pins	1.49	1.51	1.49
Sensor and cover	1.18	1.19	1.18
RF chassis, cover	1.44	1.45	1.44
Programmer assembly base	1.41	1.42	1.41
Rear structure rim	1.23	1.24	1.23
Rear structure, self load	1.29	1.30	1.29
Reaction at rear structure seat	1.22	1.23	1.22
Average overload	1.43	1.44	1.43
Temperature conditioning	-35 F	+135 F	-35 F

[a] *Test I was fired vertically at Aberdeen Proving Ground, Edgewood Area, in a "bucket."*

On disassembly, the following observations were made. Both the specially heat-treated studs and the design studs were bent. This was evident in both the hot and cold rounds. In all three fuzes, the power supply housing potting was badly broken up at the bottom of the housings. The potting material around the walls was not broken, but the bond between the potting and housing had failed. This failure was determined to be from an improper simulation of the battery pack. The pins in the power supply housing flange were bent slightly from the 1.50 overtest created by the polar moment of the spoiler plate. The memory/timing support plates were bowed slightly. The bowing was expected in the overtest and is not considered serious, since the battery pack controls the amount the plate can yield.

For the second test, the power supply housings were repotted and new flange pins were used. A new battery pack mockup was devised to better simulate the load distribution. This was done by stacking a steel cylinder and an inert power supply on an actual battery base plate. All the fiberglass boards were replaced with the actual multilayer printed-circuit boards and weighted in the same manner. This was done to verify the adequacy of the potting adhesion to the power supply housing at -35 F under maximum design load. Two types of programmer mounting-block studs were incorporated in this test. In fuzes 1 and 3, 5-40 UNC specially heat-treated 17-4 PH stainless steel studs were used. In fuze 2, 4-40 UNC heat-treated maraging steel studs were used. All fuzes were assembled with a 2-in. diam mass on the forward assembly to reduce the polar moment transmitted through the flange pins and still provide an overload on the outer shell.

The fuzes were assembled in the "bucket rounds" and fired vertically at APG. Fuzes 1 and 2 were temperature conditioned to -35 F, and fuze 3 was conditioned to +135 F. The setback accelerations the fuzes experienced on this test were 10,000 g for fuzes 1 and 2, and 10,100 g for fuze 3. The resulting load factors are shown in table 11.

The fuzes were inspected after recovery. The potting in the bottom of the power supply housings was indented but not broken. However, there was a small crack in the potting on the side of the housings that were in the two cold fuzes. The new programmer mounting-block studs were not bent in this test. The memory/timing support plate was bowed up slightly. This could occur when the round experiences compression release either at ground impact or at the muzzle of the gun. Again, the small amount of yielding was not considered serious.

TABLE 11. TEST II--PERCENTAGE OVERTEST BY WEIGHT AND FIRING CONDITIONS[a]
(14 April 1976)

Location	Fuze no.		
	1	2	3
Memory/timing boards, base	0.96	1.28	1.31
Power supply housing wall, above flange	1.81	1.80	1.83
Power supply housing base	0.93	1.14	1.16
Power supply housing wall, below flange	0.93	1.12	1.14
Power supply housing flange	1.10	1.25	1.28
Power supply housing flange pins	1.11	1.25	1.28
Sensor and cover	1.20	1.19	1.21
RF chassis, cover	1.20	1.19	1.21
Programmer assembly base	1.24	1.23	1.25
Rear structure rim	1.08	1.13	1.15
Rear structure, self load	1.24	1.23	1.25
Reaction at rear structure seat	1.08	1.11	1.14
Average overload	1.16	1.24	1.27
Temperature conditioning	-35 F	-35 F	+135 F

[a]*Test II was fired vertically at Aberdeen Proving Ground, Edgewood Area, in a "bucket."*

The three fuzes were reassembled with the same weight factors as in the first test, with one exception. In preparation for vertical gun firing at APG from a 155-mm cannon, a spoiler plate was mounted to the nose of the fuze because the "bucket" cannot be used on the M735/155-mm projectile. Previously, the 5-in. diam spoiler overstressed the power supply housing flange pins when fired at design setback acceleration. The M4A2 heated charge produces approximately 1.25 times this force. For this reason, a smaller 3.75-in. diam spoiler plate was used.

The power supply housings were all repotted, one with the wiring harness installed. Fuzes 2 and 3 were assembled with the 4-40 UNC maraging steel programmer mounting-block studs and fuze 1 with the 5-40 UNC 17-4 PH stainless steel studs. The assembled rounds were taken to the nondestructive test section of APG for a dynamic balance check. This was necessary because there had been a vertical flight stability problem with previous M735/155-mm rounds. The static and dynamic imbalance as well as transverse and polar moments of the rounds were compared to the numbers of actual M101 and M107 rounds. No extraordinary values were found.

Fuze 2 was fired vertically on 21 May 1976. The round went unstable and landed sideways on an asphalt road behind and to the left of the gun. The impact is shown in figure 14. The spoiler plate was never found, but the impression left on the road indicates that it was attached at impact (fig. 15). It was determined that the smaller spoiler plate was ineffective at the higher velocities produced by the gun and charge. Firing was terminated for the day. It was decided that fuzes 1 and 3 be fired down-range on PXR 6165 parachute recovery rounds at YPG.

Figure 14. Group 5 structural fuze, hard impact.

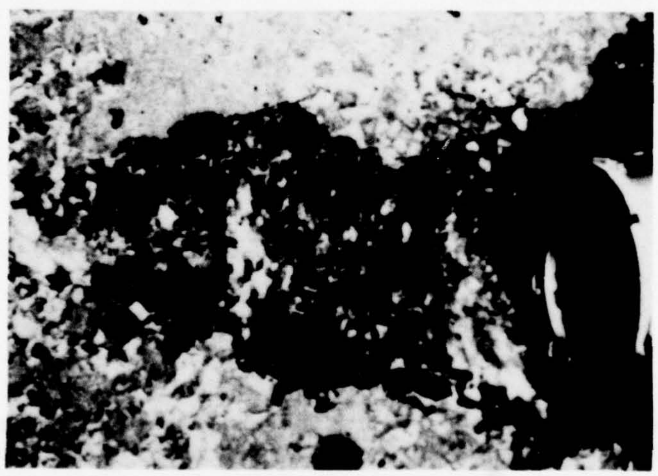

Figure 15. Group 5 structural fuze, impact crater.

The two fuzes were fired cold using the PXR 6165 projectile at YPG. Fuzes 1 and 3 experienced setback accelerations of 13,000 and 13,300 g, respectively. The parachute rounds functioned properly, and the fuzes were recovered. The load factors produced are shown in table 12.

Other than slight localized yielding in the electronic boards, there was no damage to either fuze due to this overtest. The Group 5A fuze parts have been proven structurally adequate at load levels approaching the factor of safety requirement.

The 5B fuzes used the 4-40 UNC maraging steel programmer mounting-block studs as a result of the 5A tests and because the mounting block does not have to change with this selection.

TABLE 12. TEST III--PERCENTAGE OVERTEST BY WEIGHT AND FIRING CONDITIONS
(22 July 1976)

Location	Fuze no.[a,b]		
	1	2	3
Memory/timing boards, base	1.69	N	1.73
Power supply housing wall, above flange	1.25	O	1.28
Power supply housing base	1.50		1.54
Power supply housing wall, below flange	1.48	T	1.51
Power supply housing flange	1.46		1.50
Power supply housing flange pins	1.46	E	1.50
Sensor and cover	1.56		1.60
RF chassis, cover	1.56	S	1.60
Programmer assembly base	1.63	T	1.66
Rear structure rim	1.40		1.43
Rear structure, self load	1.61		1.65
Reaction at rear structure seat	1.43		1.46
Average overload	1.50	---	1.54
Temperature conditioning	-35 F	---	-35 F

[a]*Rounds 1 and 3 were fired at Yuma Proving Ground with parachute recovery.*
[b]*Round 2 was fired vertically with a spoiler plate at Aberdeen Proving Ground, Edgewood Area. Spoiler was ineffective, allowing flight instability. Fuze was destroyed on ground impact.*

The first Group 5B structural test was a vertical firing conducted at APG. Fuzes 1 and 3 were fired hot; fuzes 2 and 4 were fired cold. Setback accelerations of the four fuzes ranged from 9,800 to 10,200 g. These values produced the load factors presented in table

13. Round 3 came apart in the air when the adapter holding the fuze to the modified M106 unthreaded. The modified M106 impacted 2 s before the fuze/bucket assembly. As a result, fuze 3 was destroyed on ground impact. The other three fuzes were recovered successfully. However, they had lost the antirotation pins in the joint between the fuze/bucket assembly and the modified M106.

On inspection of the three recovered fuzes, it was found that the memory/timing support plate screws in all three were bent. No other damage was observed in fuzes 1 and 4, but fuze 2 had a sheared ballotting screw in the rf chassis, the power supply housing pins were bent slightly, and the potting in the bottom of the power supply housing was cracked.

TABLE 13. TEST IV--PERCENTAGE OVERTEST BY WEIGHT AND FIRING CONDITIONS[a]
(14 September 1976)

Location	Fuze no.			
	1	2	3[b]	4
Memory/timing boards, base	1.38	1.34	1.34	1.33
Power supply housing wall, above flange	1.56	1.51	1.51	1.49
Power supply housing base	1.21	1.17	1.17	1.16
Power supply housing wall, below flange	1.19	1.15	1.15	1.14
Power supply housing flange	1.23	1.20	1.20	1.18
Power supply housing flange pins	1.23	1.20	1.20	1.18
Sensor and cover	1.23	1.19	1.19	1.18
RF chassis, cover	1.23	1.19	1.19	1.18
Programmer assembly base	1.26	1.23	1.23	1.21
Rear structure rim	1.21	1.17	1.19	1.18
Rear structure, self load	1.29	1.25	1.25	1.24
Reaction at rear structure seat	1.17	1.13	1.13	1.12
Average overload	1.26	1.23	1.23	1.21
Temperature conditioning	+135 F	-35 F	+135 F	-35 F

[a] *Test IV was fired vertically at Aberdeen Proving Ground, Edgewood area.*
[b] *Test round 3 came apart during descent. Adapter, fuze, and bucket assembly separated from shell. Fuze was destroyed on impact.*

The three surviving fuzes were reassembled and fired down-range on the PXR 6165 projectiles at YPG. Fuzes 1 and 4 were fired cold and fuze 2 was fired hot. The hot M4A2 Zone 7 charge provided setback accelerations of 12,300, 11,700, and 12,000 g for fuzes 1, 2, and 4, respectively. Test load factors are stated in table 14.

TABLE 14. TEST V--PERCENTAGE OVERTEST BY WEIGHT AND FIRING CONDITIONS[a]
(8 October 1976)

Location	Fuze no.			
	1	2	3	4
Memory/timing boards, base	1.66	1.59	N	1.62
Power supply housing wall, above flange	1.88	1.70	O	1.83
Power supply housing base	1.45	1.40		1.41
Power supply housing wall, below flange	1.43	1.37		1.39
Power supply housing flange	1.49	1.42	T	1.45
Power supply housing flange pins	1.49	1.42	E	1.45
Sensor and cover	1.48	1.41		1.44
RF chassis, cover	1.48	1.41	S	1.44
Programmer assembly base	1.52	1.46		1.48
Rear structure rim	1.45	1.40	T	1.44
Rear structure, self load	1.56	1.49		1.52
Reaction at rear structure seat	1.40	1.34		1.37
Average overload	1.52	1.46	---	1.48
Temperature conditioning	-35 F	+145 F	---	-35 F

[a]*Test V was fired at Yuma Proving Ground with parachute recovery.*

The loads resulted in slight local yielding at the bottom corners of the memory/timing printed-circuit boards in all three fuzes. In addition, two of the connector mounting-plate mounting screws had sheared threads in fuze 1.

In preparation for the final test, the component cut-out on the memory/timing boards was made and the damaged fasteners replaced. The fuzes were fired down-range on the PXR 6165 at YPG. Fuzes 1 and 4 were conditioned to -35 F, and fuze 2 was conditioned to +145 F. The ambient M4A2 Zone 7 charge with an additional 16 oz of powder produced setback accelerations of 13,500, 13,750, and 13,700 g for fuzes 1, 2, and 4, respectively. The load factors are recorded in table 15.

The M565 that deploys the parachute did not function on rounds 2 and 4. The associated structural fuzes were destroyed on ground impact.

To disassemble fuze 1, it was necessary to machine off the forward structure. Its threads had seized to the power supply housing threads. The rear structure suffered a small crack in the corner of the large keyway due to clockwise torque, and the rf chassis mounting holes in the center structure had elongated. The extent of the damage was minor, but it is evident that the factor of safety limits of some of the parts had been approached.

TABLE 15. TEST VI--PERCENTAGE OVERTEST BY WEIGHT AND FIRING CONDITIONS[a]
(9 February 1977)

Location	Fuze no. 1	2[b]	3	4[b]
Memory/timing boards, base	1.83	1.86	N	1.86
Power supply housing wall, above flange	2.07	2.10	O	2.10
Power supply housing base	1.60	1.62		1.62
Power supply housing wall, below flange	1.57	1.60		1.60
Power supply housing flange	1.64	1.66		1.66
Power supply housing flange pins	1.64	1.66	T	1.66
Sensor and cover	1.63	1.65		1.65
RF chassis, cover	1.63	1.65	E	1.65
Programmer assembly base	1.68	1.70		1.65
Rear structure rim	1.60	1.62	S	1.65
Rear structure, self load	1.72	1.74		1.74
Reaction at rear structure seat	1.55	1.57	T	1.57
Average overload	1.68	1.70	---	1.70
Temperature conditioning	-35 F	+145 F	---	-35 F

[a]*Test VI was fired at Yuma Proving Ground with parachute recovery.*
[b]*Parachute did not deploy on rounds 2 and 4. These structural fuzes were destroyed on ground impact.*

4.4.3 Conclusions

The gun-firing tests have verified the adequacy of the Group 5 M735 structural design. All parts have met the requirement of a 1.5 factor of safety. There are no recommended design changes as a result of the final Group 5B tests. The design is adequate and will be used for Group 6 M735 fuzes.

4.5 Group 6

The Group 6 fuze design, which was very similar to 5B, represents the DT-II*/production design configurations of the M735 fuze. A series of structural firing tests was conducted to verify the structural adequacy of the design, and also to evaluate several proposed improvements, including a new El bonding material and second-source El cover.

**Developmental Test.*

4.5.1 Description

Four structural fuzes were assembled, all having the same internal load factors. The mockup assemblies were designed to 1.25 times the weight of the electronic subassemblies they were replacing. However, when subassemblies are combined in the fuze, load factors vary. The actual fuze parts used were the forward structure, forward retainer collar, a potted supply housing without the wiring harness, center structure, rf chassis, rear structure, retainer collar, and all assembly fasteners. The El assemblies were replaced with modified blank mockups and bonded to the center structure using AF-126 film adhesive. This material had been recommended for use as being superior to the previously used AF-42 adhesive in long-term aging durability. Copper tape was wrapped on the El mockups to bring them up to actual weight. The vertical memory/timing boards were weighted with brass plates mounted with nuts and bolts. The interconnect and sensor spacers and insulators were replaced with brass plates. The programmer boards were weighted with nuts and bolts. The rf chassis was weighted with brass, and the sensor boards were replaced with brass plates. The PS416 power supply was replaced with a PS415 battery and a machined steel mockup. The overloads by weight for the two tests are shown in table 16.

Two gun-firing tests were conducted at YPG. In the first test, the fuzes were gun-fired using the 8-in. PXR 6200 parachute recovery projectile from the XM201 cannon and propelled by the XM188 Zone 9 charge, conditioned to +70 F. In the second test, the fuzes were gun fired using the 155-mm PXR 6165 parachute recovery projectile from the M1A1 cannon and the M4A2 Zone 7 charge with excess powder, conditioned to +70 F.

TABLE 16. OVERLOAD BY WEIGHT

Location	Test I	Test II
Memory/timing boards, base	1.35	1.35
Power supply housing wall, above flange	1.00	1.00
Power supply housing, base	1.30	1.18
Power supply housing wall, below flange	1.28	1.16
Power supply housing flange	1.20	1.12
Power supply housing flange pins	1.20	1.12
Sensor and cover	1.25	1.25
RF chassis, cover	1.25	1.25
Programmer assembly base	1.30	1.30
Rear structure rim	1.20	1.16
Rear structure, self load	1.30	1.30
Reaction at rear structure seat	1.17	1.15
Average overload	1.23	1.20

4.5.2 Results

In the first test, fuzes SR1 and SR3 had potential alternate source E1 covers and SR2 and SR4 had the current supplier's covers. Fuze SR1 was conditioned to -35 F and the others were fired at +135 F. The setback accelerations obtained were 8750 g. The combined weight and setback acceleration loads are shown in table 17.

Some severe damage occurred on impact. SR1, SR2, and SR3 E1 bonds had broken loose and the E1 covers were destroyed on all four. It was obvious that the covers and E1 bonding survived gun firing, since all parts were found with the fuzes in the impact holes. There was no damage to the structural parts other than a jammed forward structure that had to be machined off.

For the second test, the E1's were rebonded using the same material and the E1 covers were replaced with the current supplier's covers. The PS415 batteries were replaced with inert PS416 batteries. The structural fuzes were assembled to 155-mm PXR 6165 parachute recovery projectiles. SR1 and SR2 were temperature conditioned to -35 F, and the others to +135 F. They were fired down-range from an M1A1 cannon using 70 F M4A2 Zone 7 charge plus additional powder. The addition of powder gave erratic results in the setback acceleration force. SR1 experienced 12,700 g, with no excess powder; SR2 experienced 12,400 g, with 2 oz additional powder; SR3 experienced 12,700 g, with

TABLE 17. TEST I--PERCENTAGE OVERTEST BY WEIGHT AND FIRING CONDITIONS
(5 May 1977)

Location	Fuze no. 1	2	3	4
Memory/timing boards, base	1.15	1.13	1.15	1.12
Power supply housing wall, above flange	0.85	0.84	0.85	0.83
Power supply housing base	1.10	1.09	1.10	1.08
Power supply housing wall, below flange	1.09	1.07	1.09	1.07
Power supply housing flange	1.02	1.01	1.02	1.00
Power supply housing flange pins	1.02	1.01	1.02	1.00
Sensor and cover	1.06	1.05	1.06	1.04
RF chassis, cover	1.06	1.05	1.06	1.04
Programmer assembly base	1.10	1.09	1.10	1.08
Rear structure rim	1.02	1.01	1.02	1.00
Rear structure, self load	1.10	1.09	1.10	1.08
Reaction at rear structure seat	1.00	0.99	1.00	0.98
Average overload	1.05	1.04	1.05	1.03
Temperature conditioning	-35 F	+135 F	+135 F	+135 F

6 oz additional powder; and SR4 experienced 13,800 g, with 14 oz additional powder. SR1, SR2, and SR4 underwent hard impact because the M564 fuze inside the PXR 6165 did not function, and the test fuzes were destroyed. SR3 was recovered intact. Inspection of SR3 revealed that there was no structural damage to any Group 6 structural part. Table 18 shows the overload created by the combined overload from weight and setback acceleration.

TABLE 18. TEST II-PERCENTAGE OVERTEST BY WEIGHT AND FIRING CONDITIONS
(July 1977)

Location	Fuze no.			
	1	2	3	4
Memory/timing boards, base	1.65	1.61	1.65	1.79
Power supply housing wall, above flange	1.22	1.19	1.22	1.33
Power supply housing base	1.44	1.41	1.44	1.57
Power supply housing wall, below flange	1.42	1.38	1.42	1.54
Power supply housing flange	1.37	1.34	1.37	1.49
Power supply housing flange pins	1.37	1.34	1.37	1.49
Sensor and cover	1.53	1.49	1.53	1.66
RF chassis, cover	1.53	1.49	1.53	1.66
Programmer assembly base	1.59	1.55	1.59	1.73
Rear structure rim	1.42	1.38	1.42	1.54
Rear structure, self load	1.59	1.55	1.59	1.73
Reaction at rear structure seat	1.40	1.37	1.40	1.53
Average overload	1.46	1.43	1.46	1.60
Temperature conditioning	-35 F	-35 F	+135 F	+135 F

4.5.3 Conclusions

The gun-firing tests verified the adequacy of the structural design of the Group 6 fuze, including the AF-126 bonding material and the alternate source El cover.

5. STRUCTURAL FIRING SUMMARY

In summary, a total of 37 gun-firing tests of M735 structural fuzes has been conducted. In all these tests, no failure of any major structural part of the fuze has been observed. A number of minor component failures occurred and have been corrected in subsequent design iterations. The firing tests are summarized in table 19. In addition to verifying the adequacy of the structural parts and refining the details of the mechanical design, substantial fuze weight reductions were achieved primarily as a result of this firing program. In fact, the overall fuze weight has been reduced from the initial Group 1 weight of 11.4 lb (5.2 kg) to the present Group 6 weight of 10.5 lb (4.8 kg).

TABLE 19. M735 FUZE STRUCTURAL GUN-FIRING TESTS

Test date	Weapon	Propellant	Fuze S/N	Fuze temperature (F)	Setback (g)	Load[a] factor	Observations
Group 4A/B							
2 July 1975	8-in. XM201 tube	XM188, Zone 9, 145 F	S-4A-1	--	10,650	1.00	Severe transverse loads; programmer mounting blocks failed.
			S-4A-2	--	10,500	1.00	No damage.
20 August 1975	8-in. XM201 tube	XM188, Zone 9, 135 F	S-4A-1	--	10,500	1.20	Programmer mounting screws yielded.
			S-4A-2	--	10,550	1.20	No damage.
16 September 1975	155-mm M1A2 tube	M4A2, Zone 7, +7 oz, 145 F	S-4A-1	--	12,500	1.45	No damage.
			S-4A-2	--	12,500	1.45	Experimental cover failed.
Group 4C/D							
23 October 1975	155-mm M1A2 tube	M4A2, Zone 7, +11 oz, 145 F	S-4C-1	--	15,000	1.45	No test.
			S-4C-2	--	15,200	1.80	Cover antirotation pin failed.
			S-4C-3	--	15,000	2.15	Cover antirotation pin failed.
4 December 1975	155-mm M1A2 tube	M4A2, Zone 7, 145 F	S-4C-2	--	13,750	1.30	No damage.
			S-4C-3	--	13,150	1.60	No damage.
Group 5A							
18 March 1976	8-in. XM201 tube	XM188, Zone 9, 135 F	S-5A-1	-35	10,400	1.43	Programmer mounting studs yielded;[b] power supply housing potting cracked.[c]
			S-5A-2	+135	10,500	1.44	Programmer mounting studs yielded; power supply housing potting cracked.
			S-5A-3	-35	10,400	1.43	Power supply housing potting cracked.
15 April 1976	8-in. XM201 tube	XM188, Zone 9, 135 F	S-5A-1	-35	10,000	1.16	No damage.
			S-5A-2	-35	10,000	1.24	No damage.
			S-5A-3	+135	10,100	1.27	No damage
22 July 1976	155-mm M2A2 tube	M4A2, Zone 7, 145 F	S-5A-1	-35	13,050	1.50	No damage.
			S-5A-3	-35	13,280	1.54	Memory/timing center stud slightly bent; memory/timing top plug cracked; bottom corners of memory/timing boards yielded slightly.

[a] *Based on combined mass and setback overtest levels.*

[b] *Programmer mounting studs yielded slightly in first test series. High strength studs used in second test series; no yielding evident.*

[c] *Power supply housing potting cracked in first test series due to improper simulation of battery pack. Actual power supply used for second test series; no cracks evident.*

TABLE 19. M735 FUZE STRUCTURAL GUN-FIRING TESTS (Cont'd)

Test date	Weapon	Propellant	Fuze S/N	Fuze temperature (F)	Setback (g)	Load[a] factor	Observations
Group 5B							
14 September 1976	8-in. XM201 tube	XM188, Zone 9, 135 F	S-5B-1	+135	10,200	1.26	Memory/timing support plate screws bent.
			S-5B-2	-35	9,900	1.23	Memory/timing support plate screws bent; power supply housing potting broke around bottom; power supply housing pins bent.
			S-5B-3	+135	9,900	1.23	Destroyed on ground impact.
			S-5B-4	-35	9,800	1.21	Memory/timing support plate screws bent.
8 October 1976	155-mm M2A2 tube	M4A2, Zone 7, 145 F	S-5B-1	-35	12,300	1.52	Memory/timing board corners yielded slightly.
			S-5B-2	+145	11,700	1.46	Memory/timing board corners yielded slightly.
			S-5B-4	-35	12,000	1.48	Memory/timing board corners yielded slightly.
9 February 1977[d]	155-mm M2A2 tube	M4A2, Zone 7, +16 oz, ambient temperature	S-5B-1	-35	13,500	1.68	Small crack at top of large keyway on rear structure--cw torque
			S-5B-2	+135	13,750	1.70	Destroyed on ground impact.
			S-5B-4	-35	13,700	1.70	Destroyed on ground impact.
Group 6							
24 May 1977	8-in. XM201 tube 60% wear	XM188, Zone 9, 70 F	S-6-1	-35	8,860	1.05	Impacted in hard ground; E1 cover damaged; E1 bond broken loose.
			S-6-2	+135	8,720	1.04	Impacted in hard ground; E1 cover missing; E1 bond broken loose.
			S-6-3	+135	8,820	1.05	Impacted in hard ground; E1 cover damaged; E1 bond broken loose; forward structure jammed.
			S-6-4	+135	8,670	1.03	Impacted in hard ground; E1 cover damaged.
21 July 1977	155-mm M1A1 tube	M4A2, Zone 7, 70 F	S-6-1	-35	12,690	1.46	PXR 6165 did not function properly; fuze destroyed on ground impact.
			S-6-2	-35	12,400	1.43	PXR 6165 did not function properly; fuze destroyed on ground impact.
			S-6-3	+135	12,727	1.46	No damage.
			S-6-4	+135	13,800	1.60	PXR 6165 did not function properly; fuze destroyed on ground impact.

[a]*Based on combined mass and setback overtest levels.*

[d]*On the 9 February 1977 test, the M565 fuze that deploys the parachute did not function on rounds 2 and 4.*

6. CONCLUSIONS

In conclusion, the structural fuze firing test program has resulted in an efficient, lightweight structural design for the M735 fuze. The present M735 fuze design has been proven to be structurally adequate for gun-launch loads 1.5 times greater than the design requirement. In fact, the structural fuze firing test program has proven to be a successful means of qualifying the fuze structure for gun firing. This success is demonstrated by the fact that in over 100 subsequent gun firings of functional fuzes, not one fuze has failed to perform properly due to failure of a structural part.

APPENDIX A.--FEASIBILITY OF USING BLUNT-NOSED COVER IN FUZE VERTICAL-RECOVERY FIRING TESTS

CONTENTS

FIGURES

TABLE

A-1. INTRODUCTION

Vertical-recovery testing (firing a projectile nearly vertical for base first impact and recovery) was used extensively during the XM730 fuze development program. While it generally proved to be a relatively inexpensive means of testing fuzes and components, some serious problems were encountered. In almost every case, the fuze experienced some damage during the recovery operation (digging). Also, many test projectiles fired at high zones precessed or floated during descent, causing severe fuze damage on impact. This phenomenon appeared to be peculiar to these test projectiles, which have a long slim ogive relative to standard projectile shapes.

A blunt-nosed metal cover was proposed, which would completely cover the fuze and thus protect it during the recovery operation. The blunt nose would drastically increase projectile drag, and thereby minimize descent velocity. It was expected that this would prevent projectile instability, since it only occurred on high zone shots where the projectile achieved transonic descent velocity.

A-2. TEST DESCRIPTION AND RESULTS

Six M106 projectiles were modified and fitted with mockup fuzes ballistically similar to the M735 fuze. Blunt-nosed covers were mounted on three of the test rounds. The covers were fabricated from aluminum tubing (7-in. o.d., 0.25-in. wall), with a plate welded to the forward end and threaded to the projectile just aft of the projectile-fuze interface. Two of the test rounds, one with cover and one without, are shown in figure A-1.

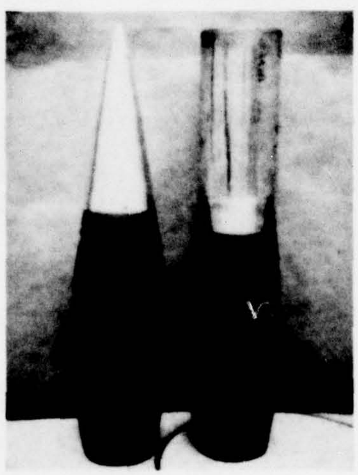

Figure A-1. Typical test rounds before firing.

APPENDIX A

All six rounds were fired vertically at APG from the XM201 cannon at Zone 7. Firing data are summarized in table A-1.

TABLE A-1. FIRING DATA

Round No.	Description	Weight (lb)[a]	Breech pressure (psi)[b]	Acceleration (g)
1	without cover	192	28,800	7,030
2	without cover	192	29,300	7,150
3	without cover	192	29,300	7,150
4	with cover	188	29,200	7,270
5	with cover	188	29,300	7,300
6	with cover	188	29,300	7,300

[a] *lb × 0.453592 = kg.*
[b] *psi × 6894 = Pa.*

The three test rounds without covers floated during descent. Two of the three were subsequently recovered, and are shown in figure A-2. Of the two, one fuze was severed from the projectile at impact, and the other was considerably damaged during the recovery operation. Penetration depths were 2 and 4 ft (0.6 and 1.2 m).

Figure A-2. Recovered rounds without cover.

None of the three rounds with covers floated during descent. All three rounds were subsequently recovered, and are shown in figure A-3. Of the three rounds, two were found intact, with no resulting damage to the fuzes. The cover of the third round was found separated from the projectile. This fuze experienced some minor damage during the recovery operation. Penetration depths ranged from 15 to 20 ft (4.6 to 6.1 m).

Figure A-3. Recovered rounds with cover.

A-3. CONCLUSIONS AND RECOMMENDATIONS

From these tests, it can be concluded that a blunt-nosed cover of this type will eliminate projectile instability during descent, and protect the fuze during the recovery operation. Although one cover did fail at impact, a slight redesign of the cover (i.e., increased wall thickness) should prevent this from occurring in the future.

Of course, the major disadvantage of a cover of this type is that it precludes a fuze functional test during flight. However, the installation of a flat 7-in.-diam (~178-mm-diam) washer at the fuze nose would increase projectile drag the same as the blunt cover and would allow fuze function. While this washer obviously would not protect the fuze as much as the cover would during the recovery operation, it would prevent projectile instability during descent and resultant severe fuze damage.

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